An Overview of the Dynamics of the Mesosphere and Lower Thermosphere

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SPARC Data Assimilation Workshop

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Outline of Talk

1. The MLT: a wave-driven circulation
2. Tides, planetary waves & gravity waves observed from space
3. Vertically extended GCMs:
   - → General description
   - → Comparisons to observations
   - → Interpretation of observations
4. Role for data assimilation

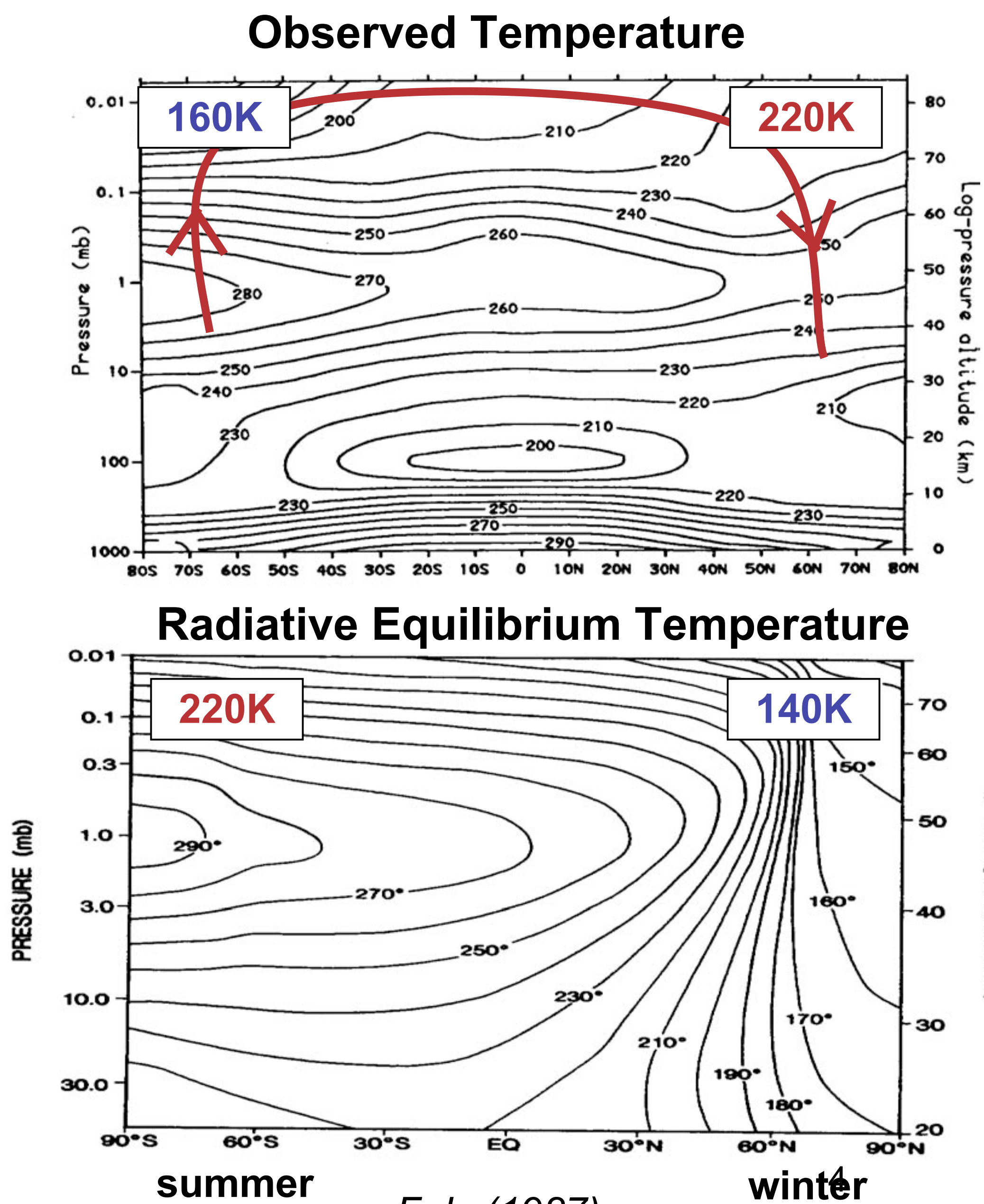
1. The MLT: a wave-driven circulation

Extra-tropics

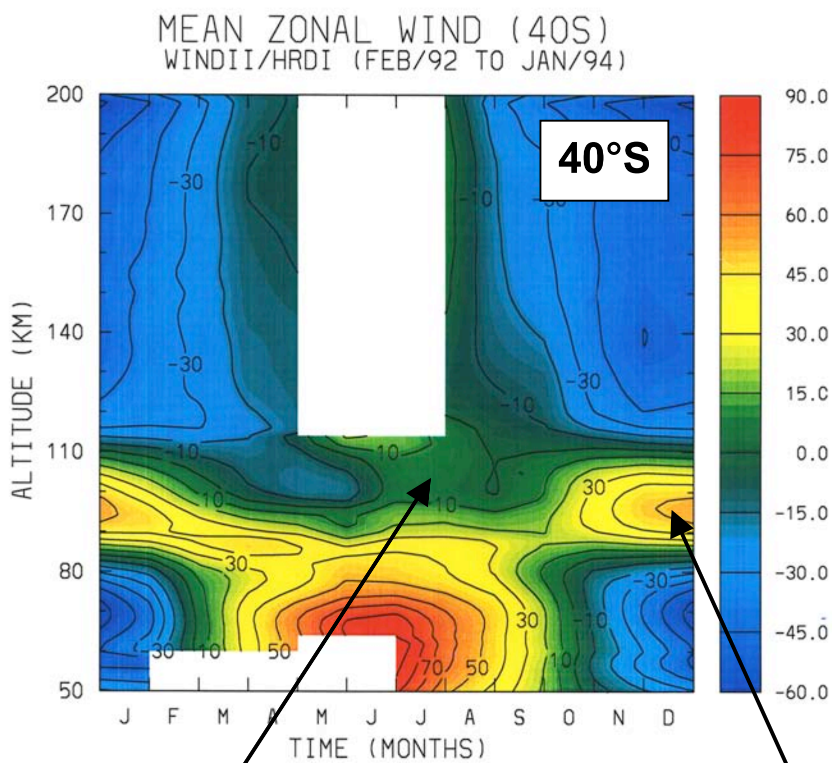
→ But the observations show the opposite.

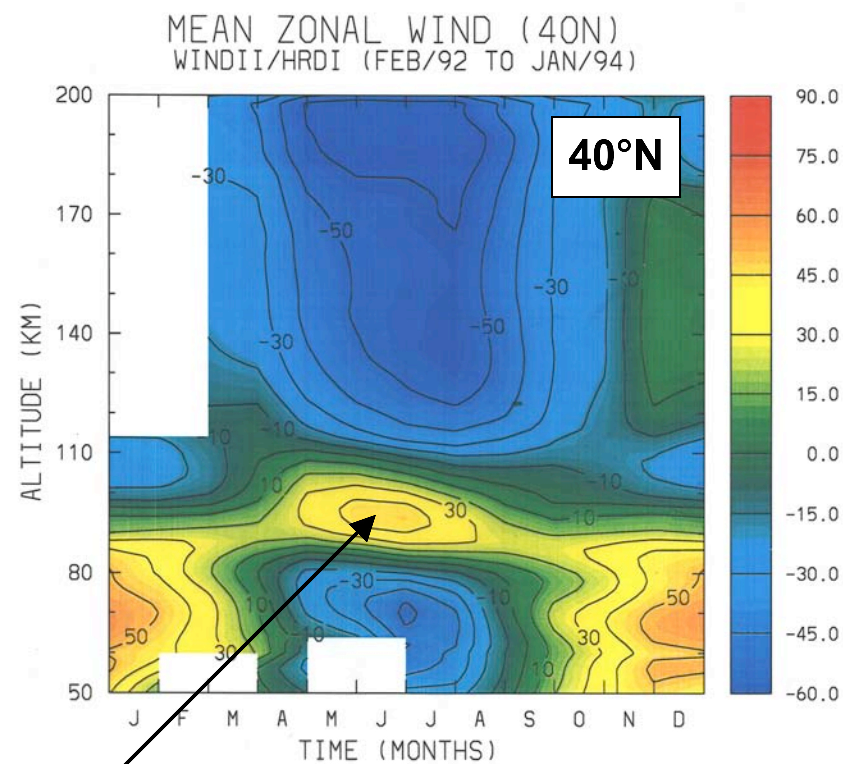
→ Why? Because of the dynamical heating (cooling) that results from gravity wave drag in the mesosphere.

→ In the absence of dynamics, radiation would result in a warm summer mesosphere and a cold winter mesosphere.



Fels (1987)

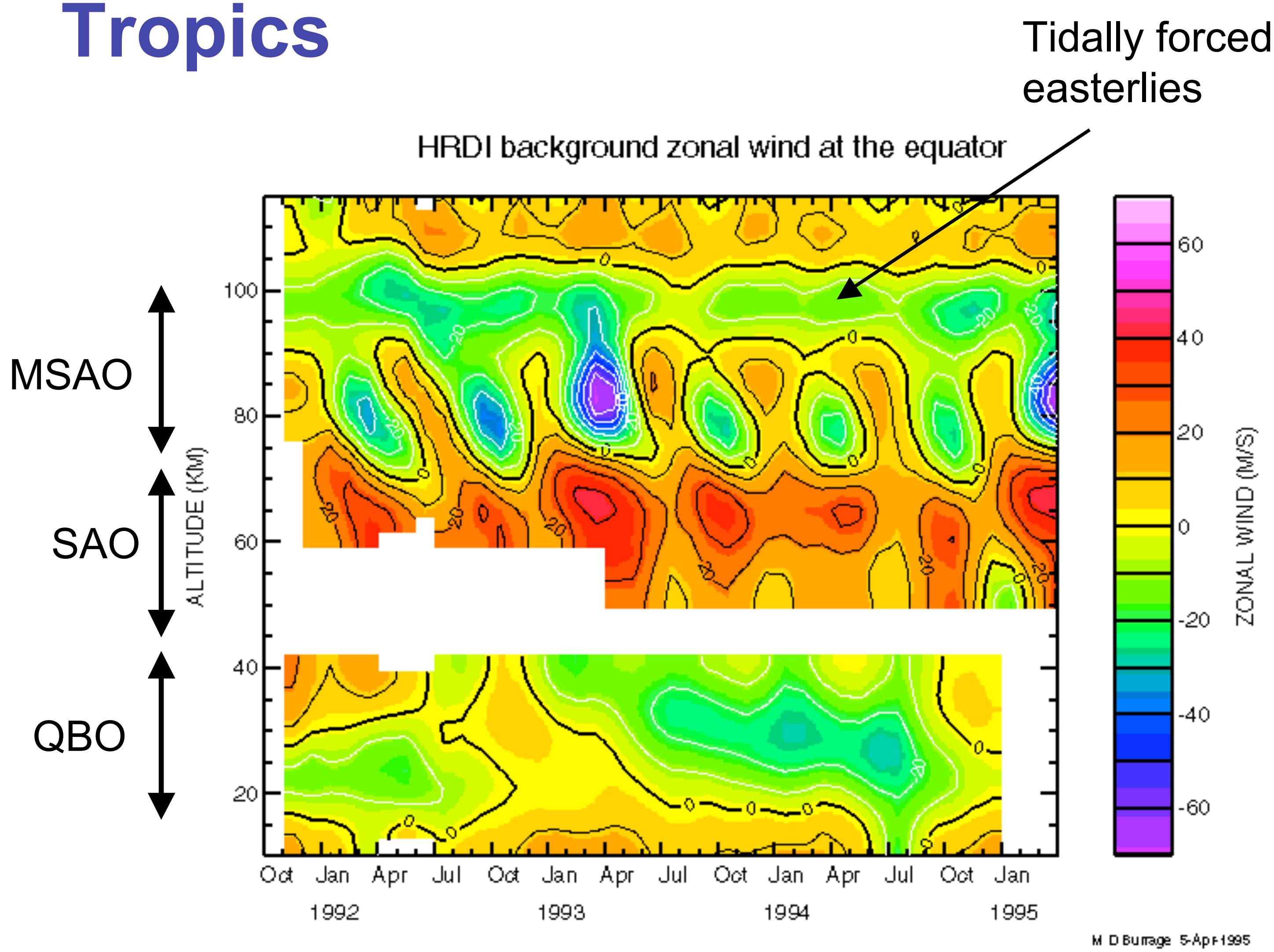




Closing off of winter westerlies

Reversal of summer easterlies

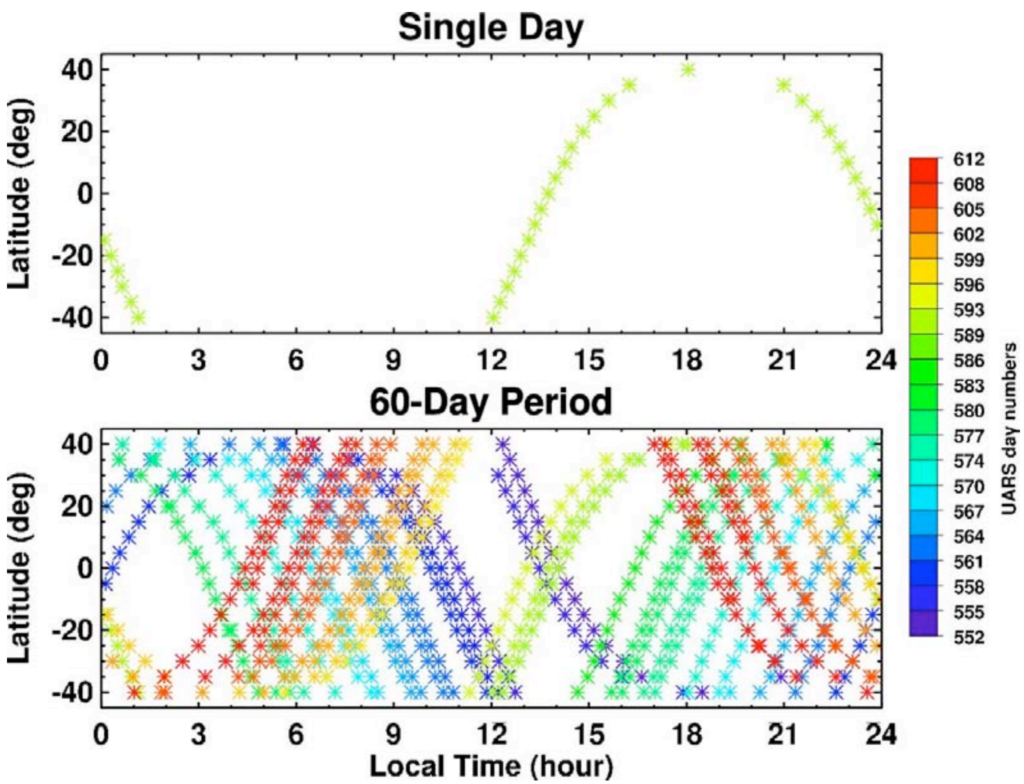
Tropics

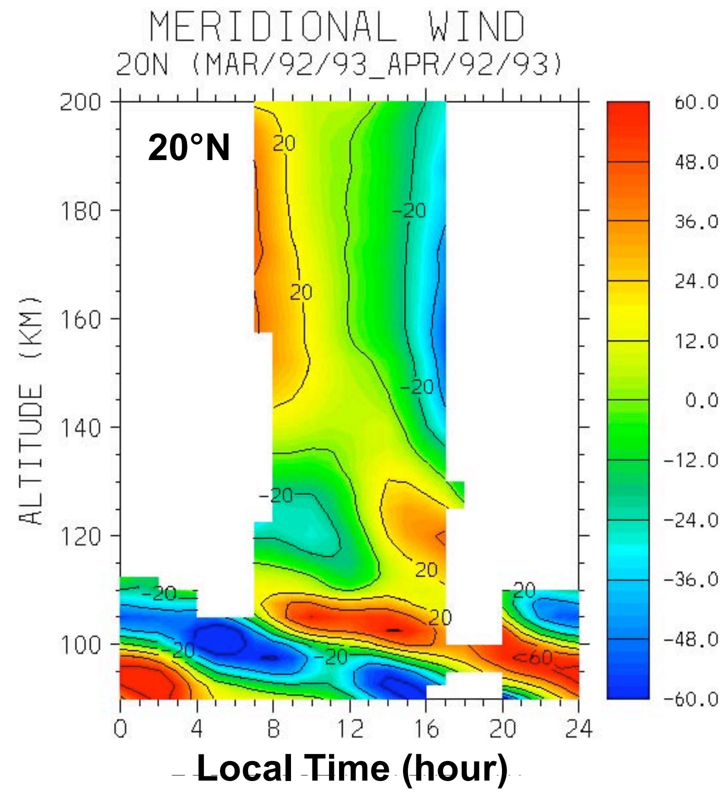


Burrage et al. (1996)

2. Tides, Planetary Waves & Gravity Waves Observed from Space

Satellite Sampling Issues

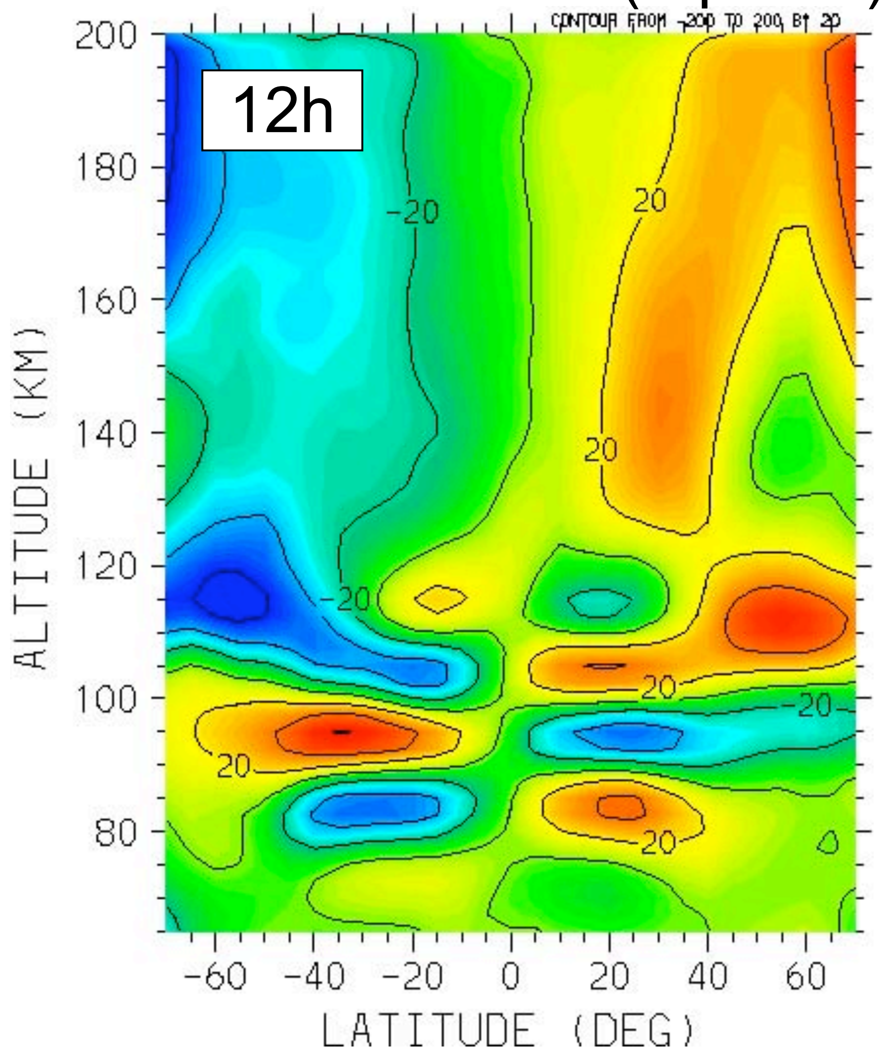


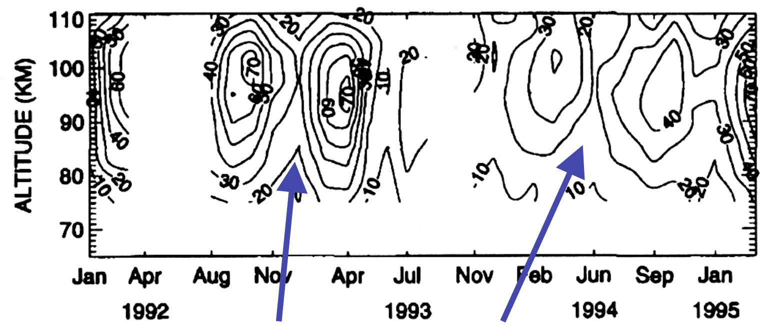


⇒ Many days are required to sample all local times at a fixed latitude - this will cause aliasing when satellite data are binned in local time.

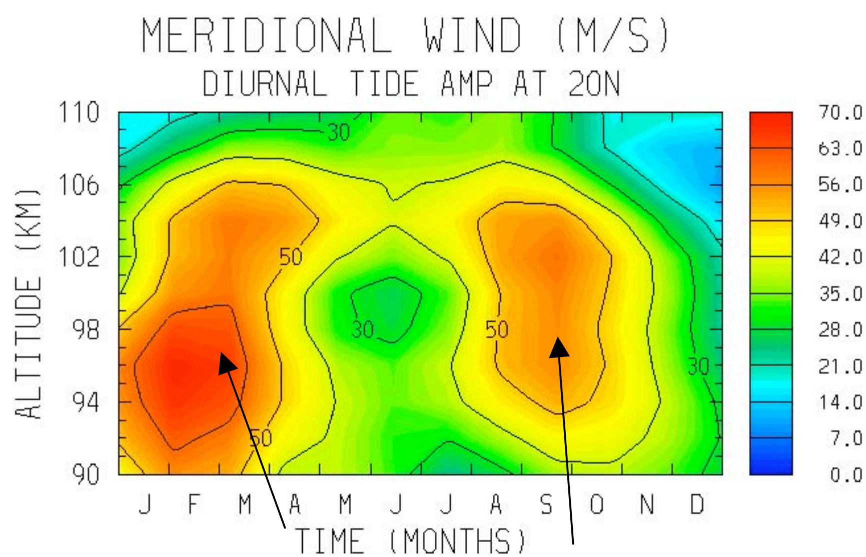
Migrating (sun-synchronous) Diurnal Tide

meridional wind (equinox)





Interannual variations
(possibly linked to QBO)



Maximum amplitude
at equinoxes

McLandress et al (1996)

Migrating Semi-diurnal Tide

meridional wind

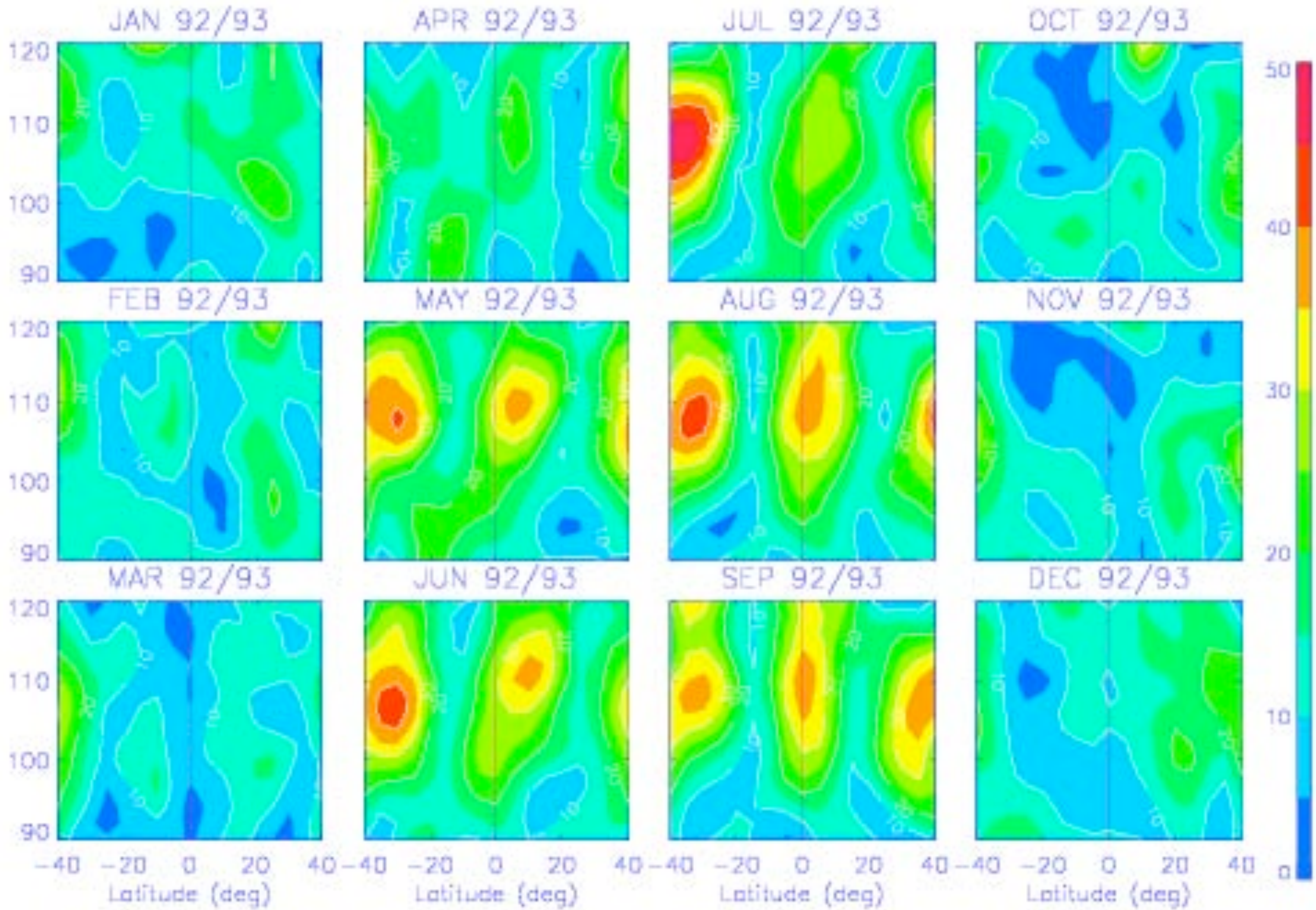
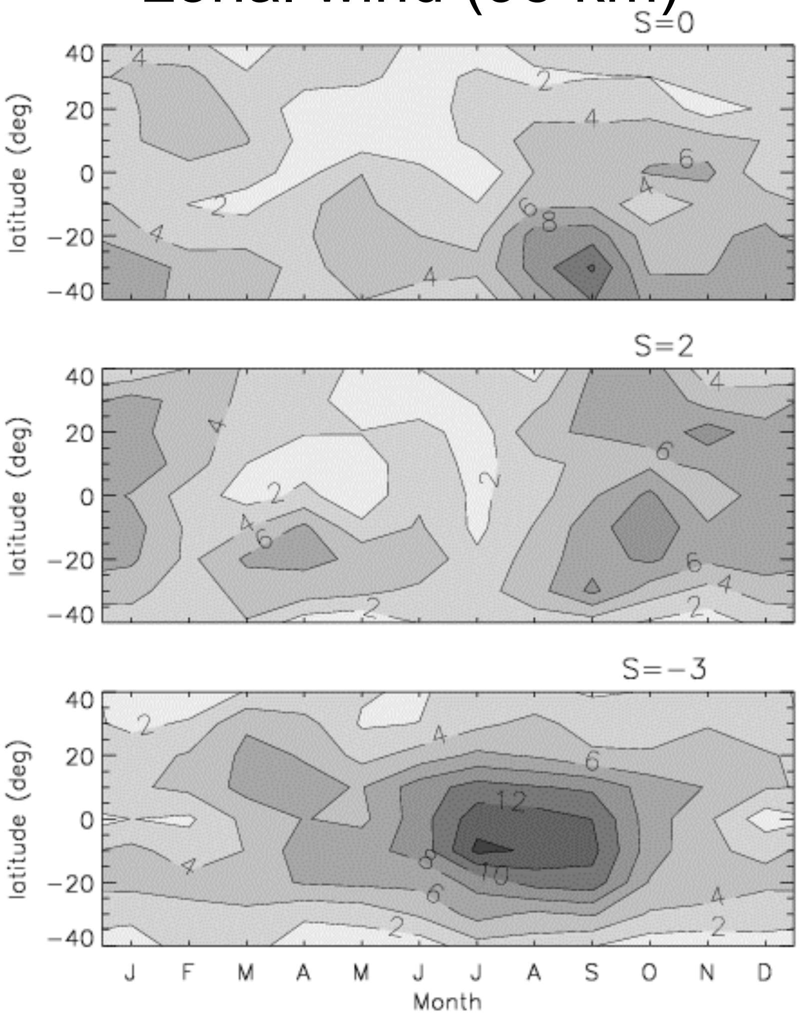


Figure courtesy of Shengpan Zhang

Non-migrating Diurnal Tides

zonal wind (95 km)



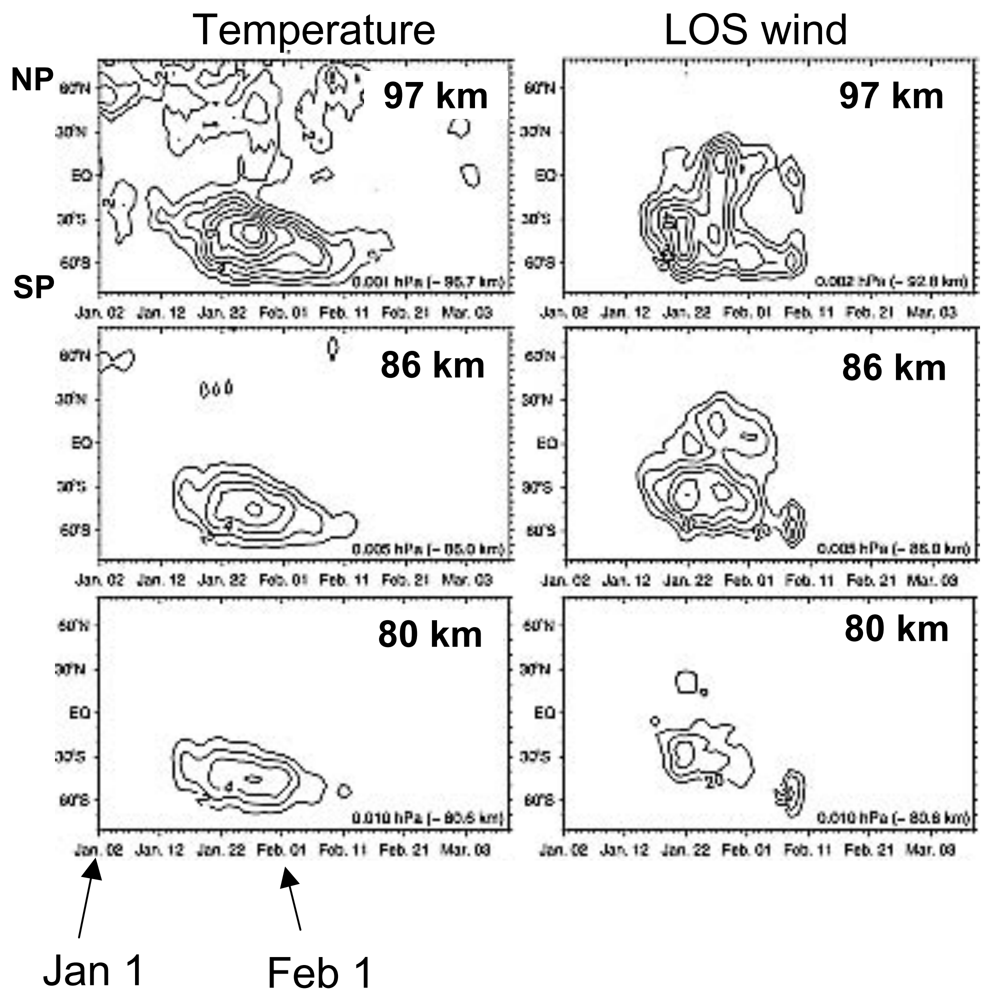
zonal mean

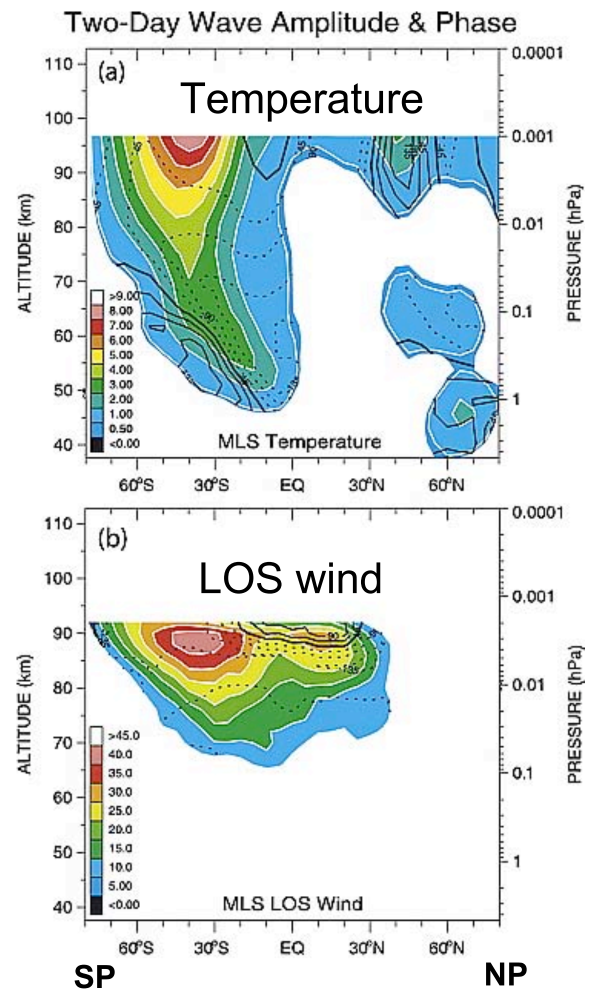
westward wave 1

eastward wave 3

Forbes et al (2003)

Two-Day Wave

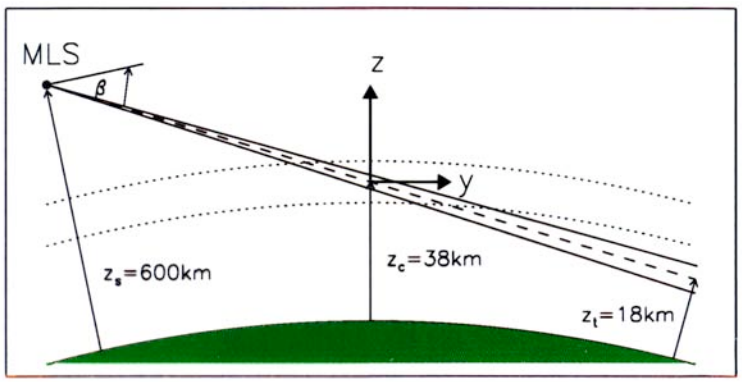




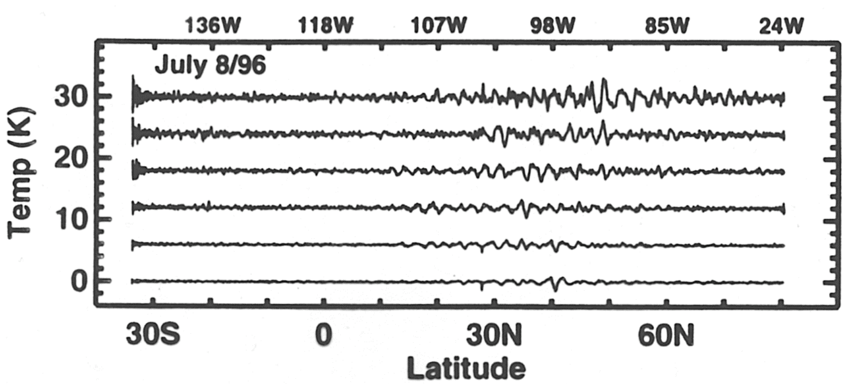
Limpasuvan et al (2005)

Small-Scale Gravity Waves

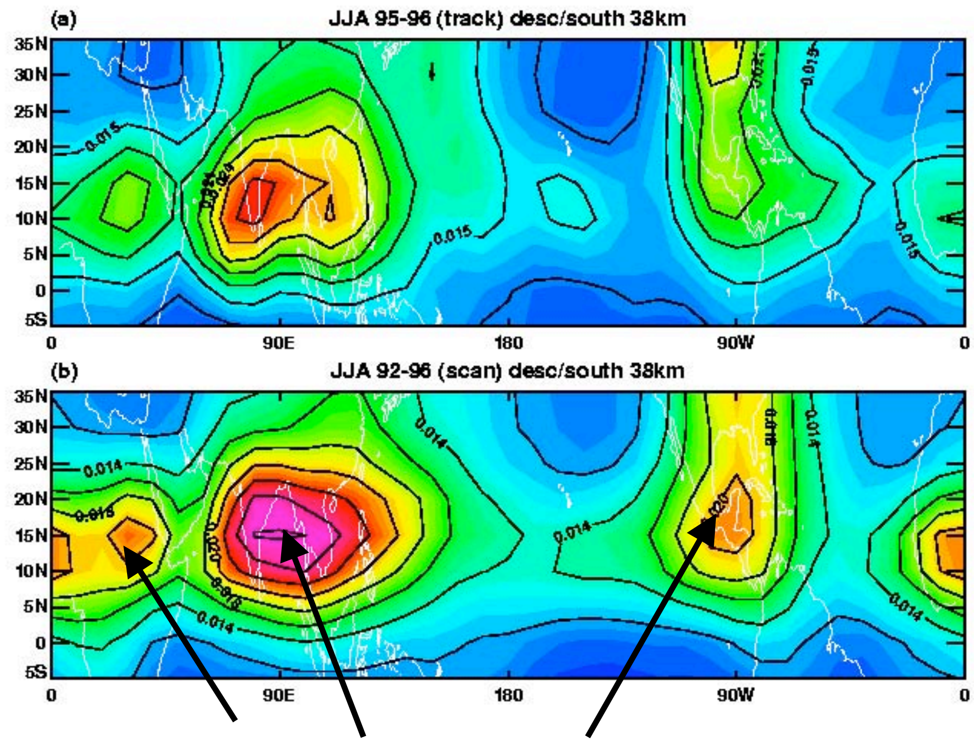
Microwave Limb Sounder geometry



Single day of temperature data



Seasonal average (NH summer)



Temperature variance strongest over convective regions

McLandress et al (2000)

3. Vertically Extended GCMs

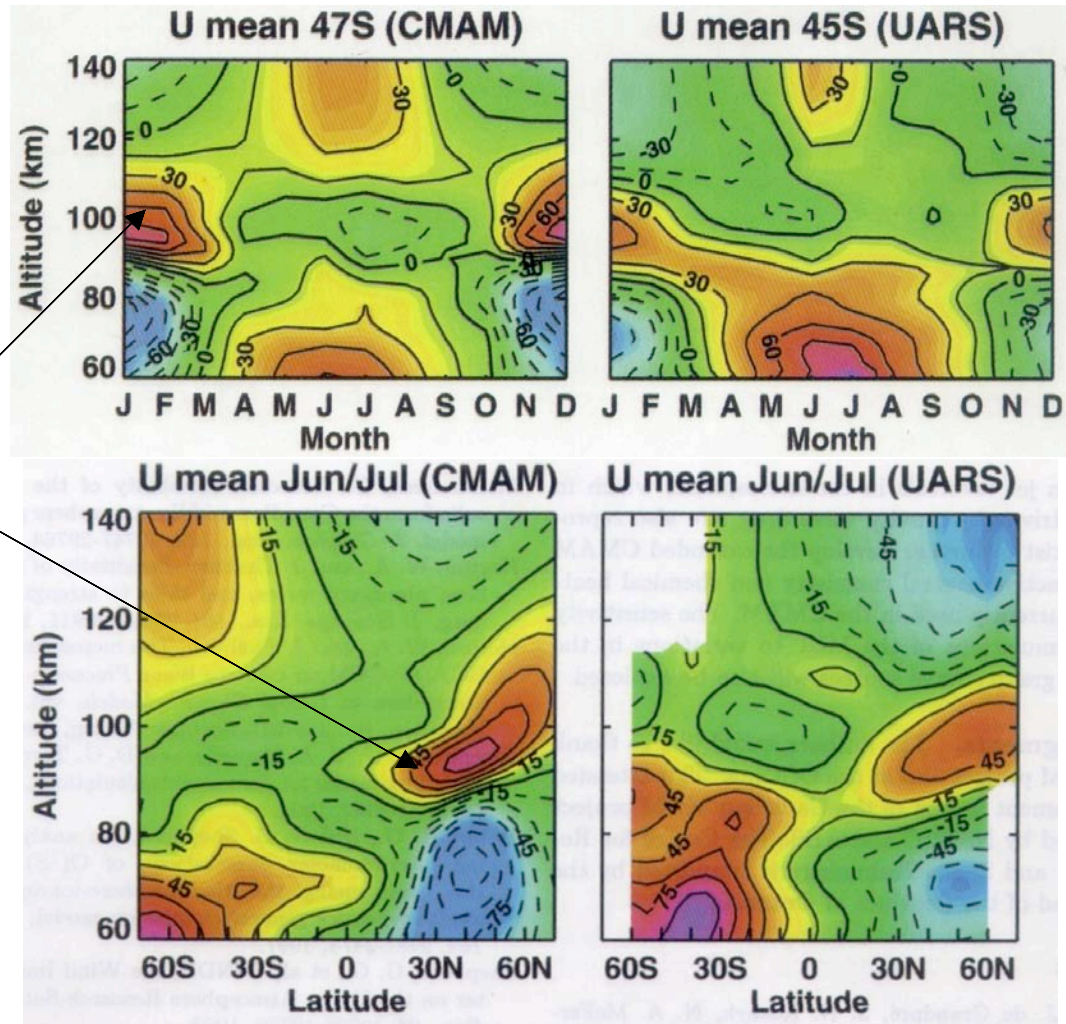
General Description

- Upper boundary above ~ 150 km
- Full suite of tropospheric parameterizations (otherwise doesn’t count as an extended GCM)
- Parameterizations relevant to the MLT (EUV solar radiation, non-LTE infrared radiation, GWD, etc.)
- Interactive chemistry possibly
- Current extended GCMs:
  - Canadian Middle Atmosphere Model (CMAM)
  - Whole Atmosphere Community Climate Model (WACCM)
  - Hamburg Model of the Neutral and Ionized Atmosphere (HAMMONIA)
- Remainder of talk focuses on CMAM

Comparisons to Observations

Zonal mean zonal winds

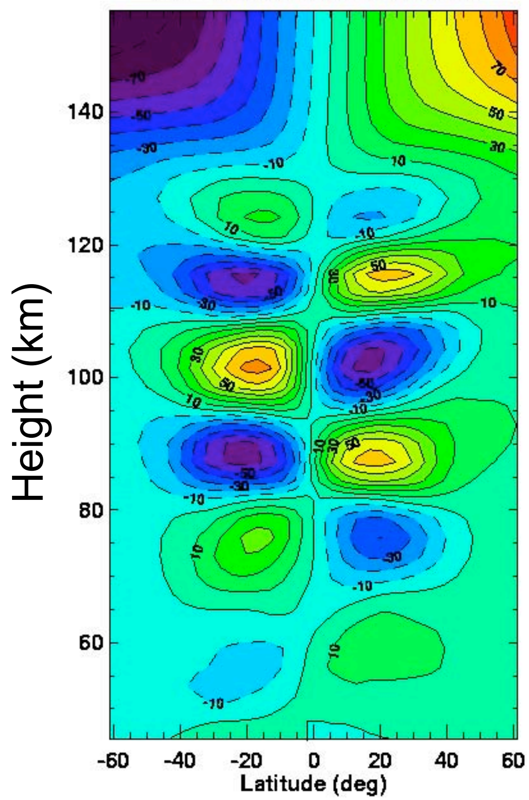
Wind reversals in MLT due to parameterized GWD



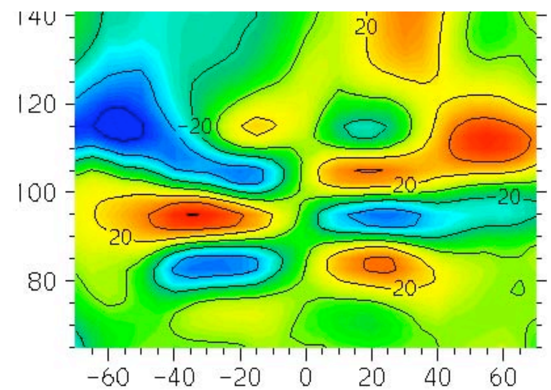
Beagley et al (2000)

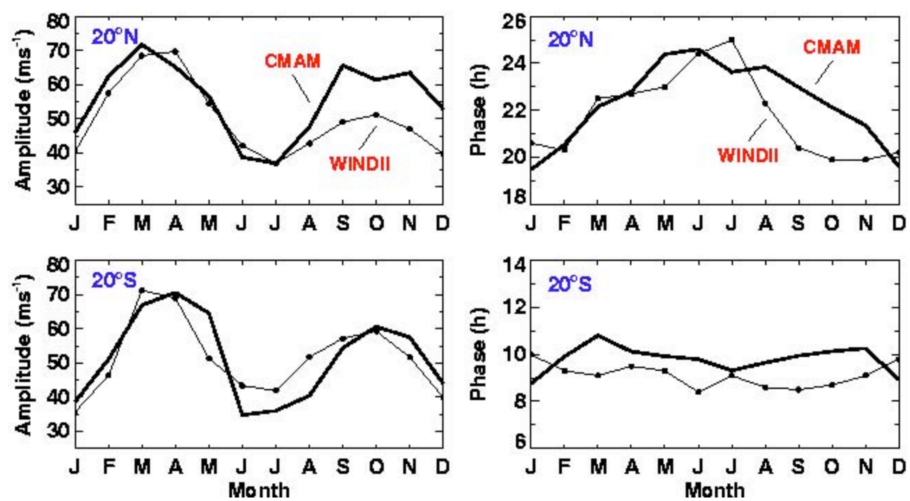
Migrating diurnal tide

CMAM



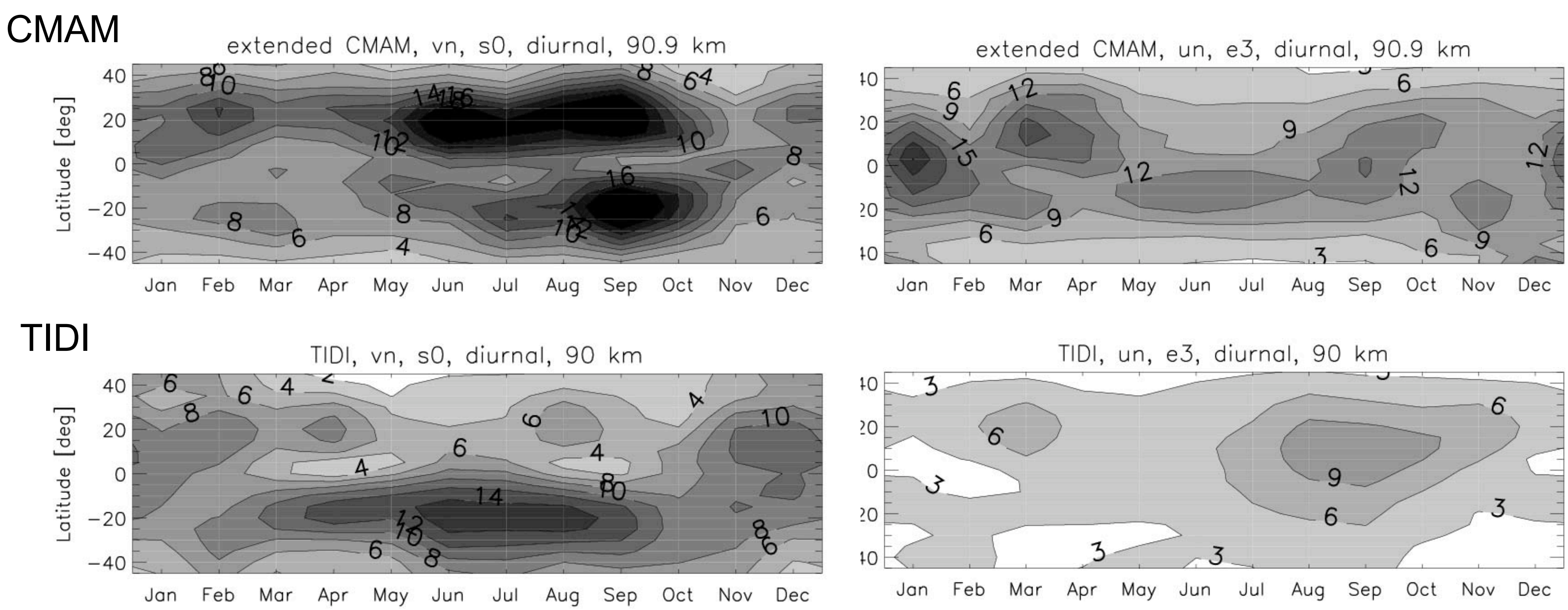
Observations





McLandress (2002)

Non-migrating diurnal tides



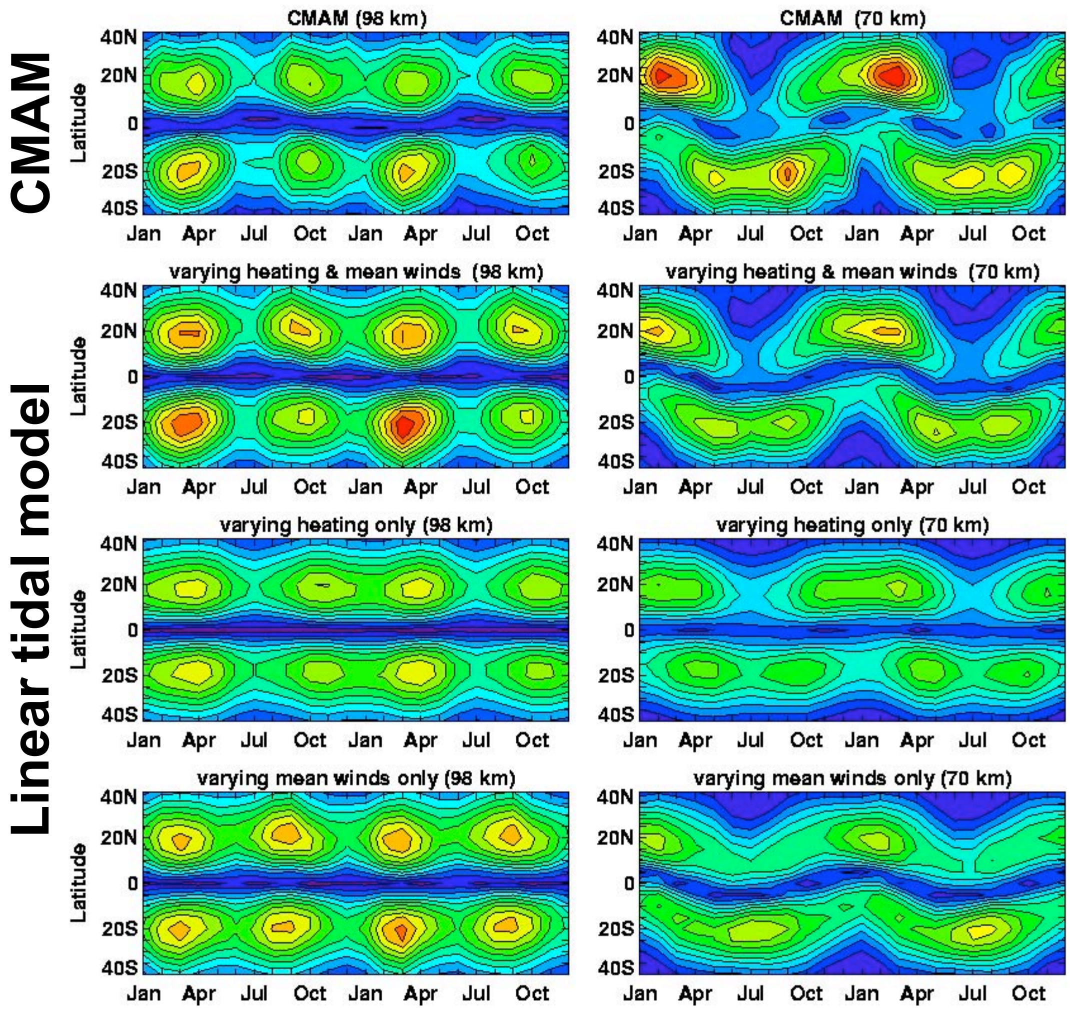
standing

eastward wave 3

Top figure courtesy of William Ward
Bottom figure courtesy of Jens Oberheide

Interpretation of Observations

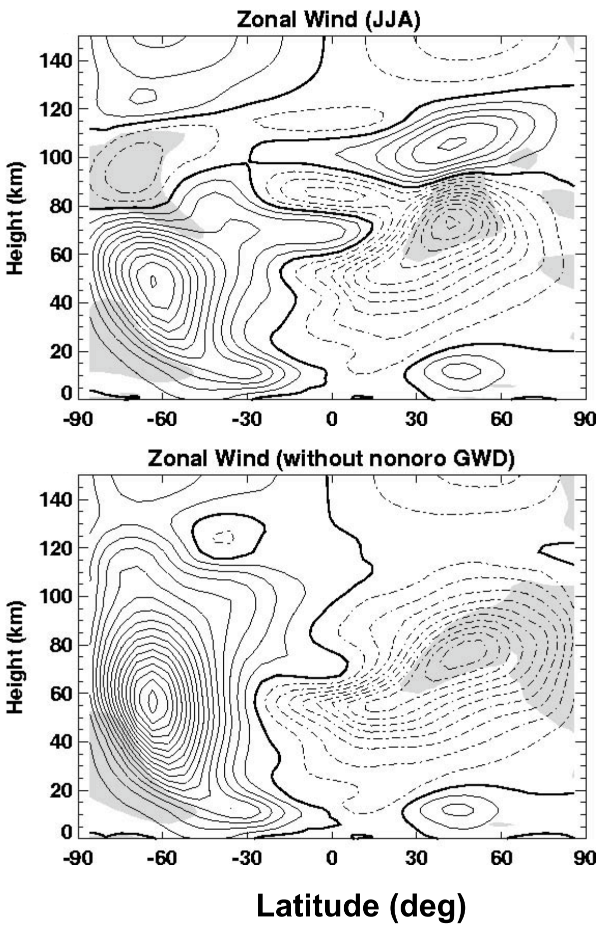
Causes of the semi-annual variation of the migrating diurnal tide

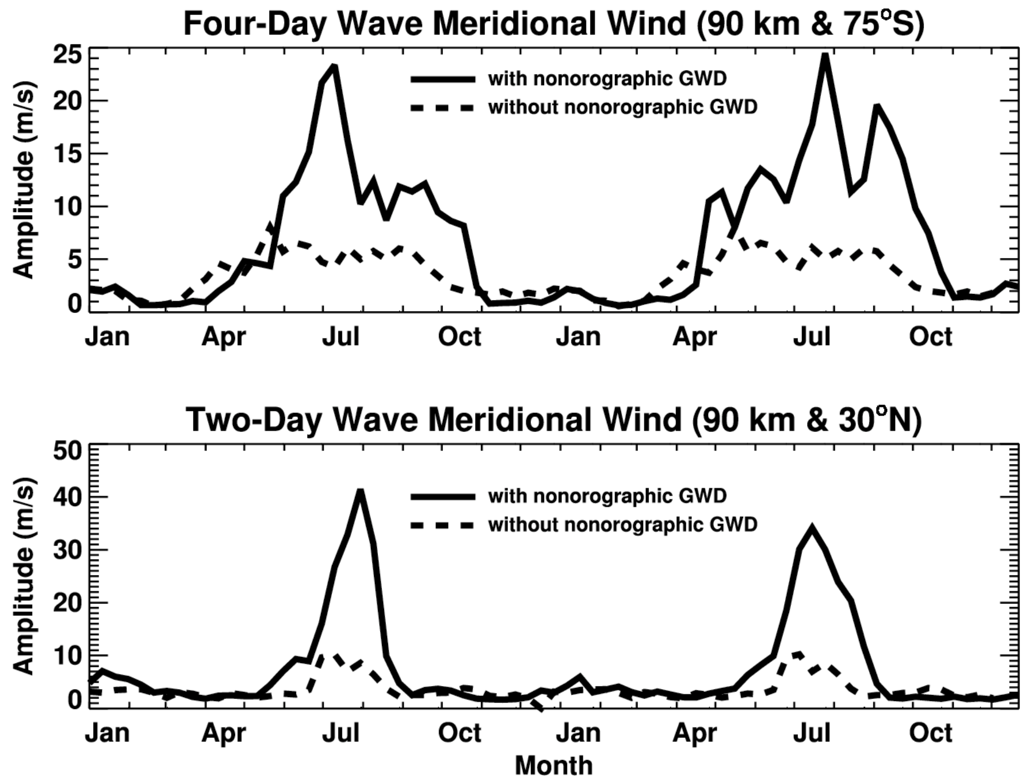


McLandress (2002)

⇒ semi-annual amplitude variation results from a combination of tropospheric heating and mean winds in the mesosphere.

Importance of GWD in generating regions of wave instability

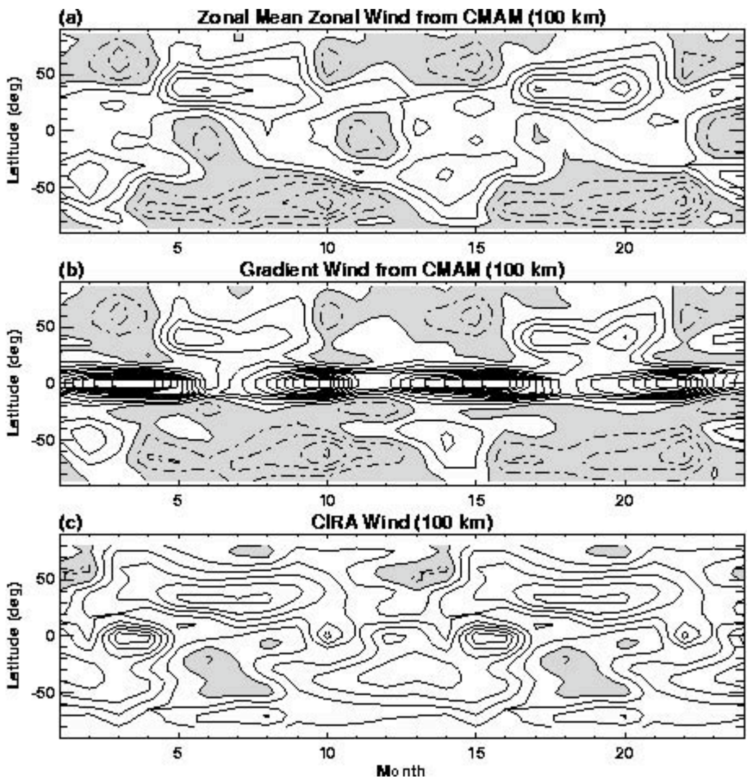




⇒ Parameterized GWD generates the zonal wind shear zones that generate the 2DW and 4DW.

McLandress et al (2006)

Deriving winds from temperatures



CMAM - actual winds

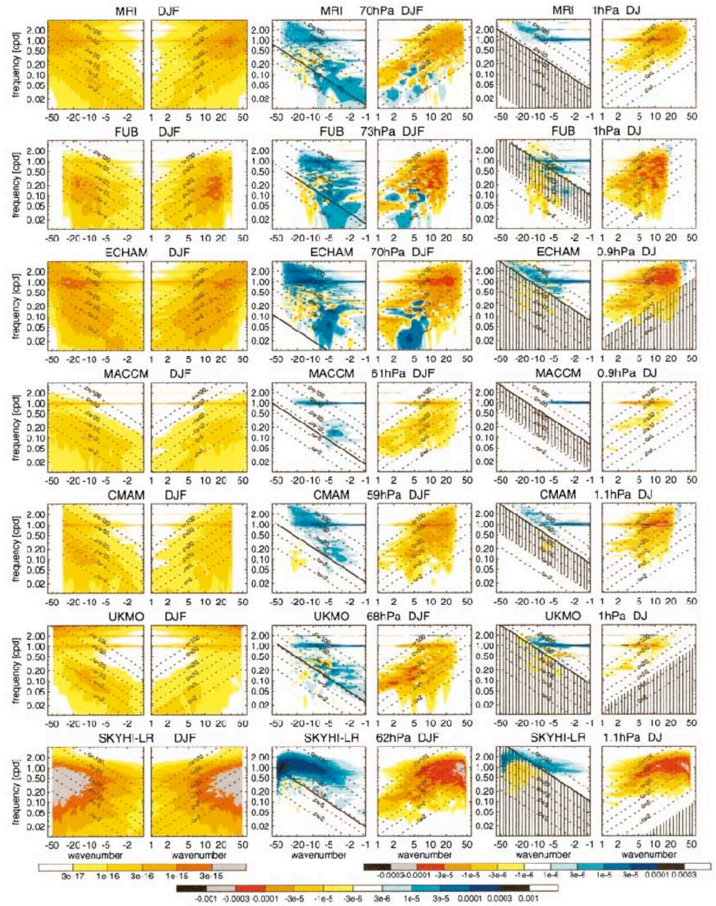
CMAM - gradient winds (derived)

CIRA - gradient winds (derived)

⇒Temperatures should not be used to estimate winds in the tropics, especially when diurnal tide is strong.

McLandress et al (2006)

Equatorial waves



precipitation ***Fz*** **(70 hPa)** ***Fz*** **(1 hPa)**

Horinouchi et al (2003)

⇒ **Equatorial wave spectra are largely controlled by the convective parameterizations.**

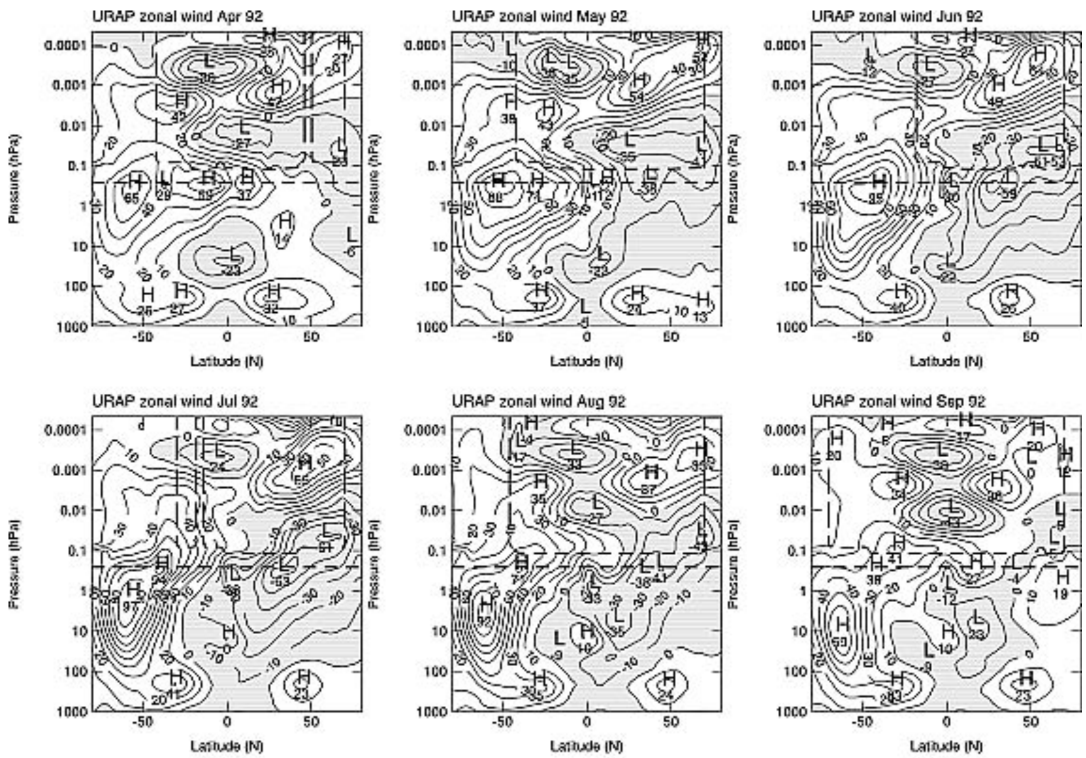
⇒ **This has important consequences for the forcing of equatorial zonal wind oscillations.**

4. Role for Data Assimilation

- The extension of DA systems into the MLT region is a new frontier.
- There are many satellite data sets of the MLT available spanning over two decades.
- DA will be able to merge these data sets in a consistent manner and provide the most reliable climatologies of the MLT region.
- Current climatologies often derived from daytime only data.

Zonal mean climatologies derived from only daytime data Climatology

UARS Reference Atmosphere Project (URAP)

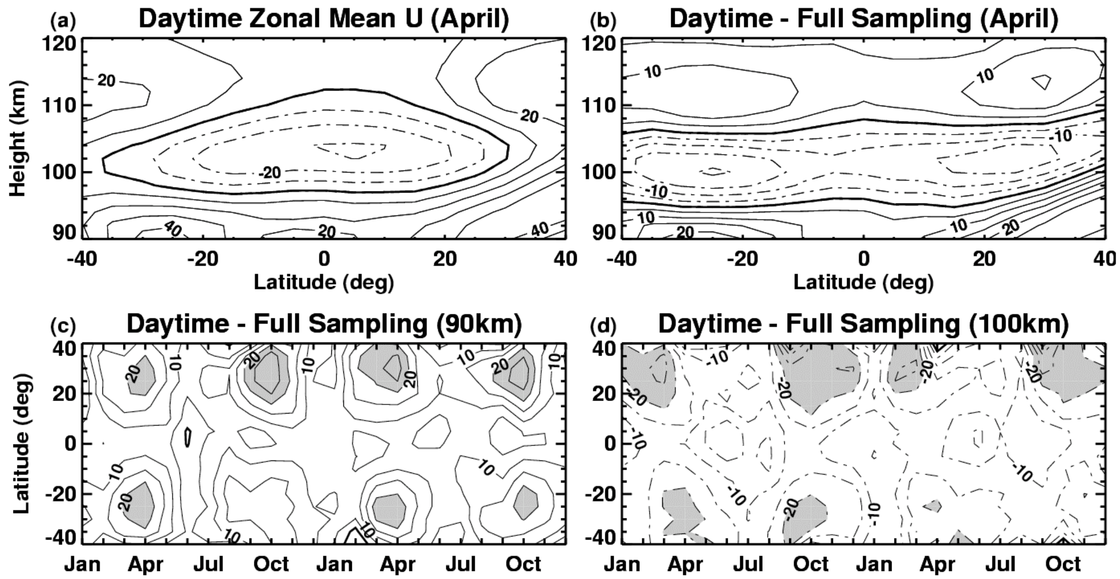


Swinbank and Ortland (2003)

In the MLT region the climatology is derived using only daytime data.

⇒ **Incomplete removal of the diurnal tide could be a problem**

Assessing impact of using daytime-only winds using CMAM



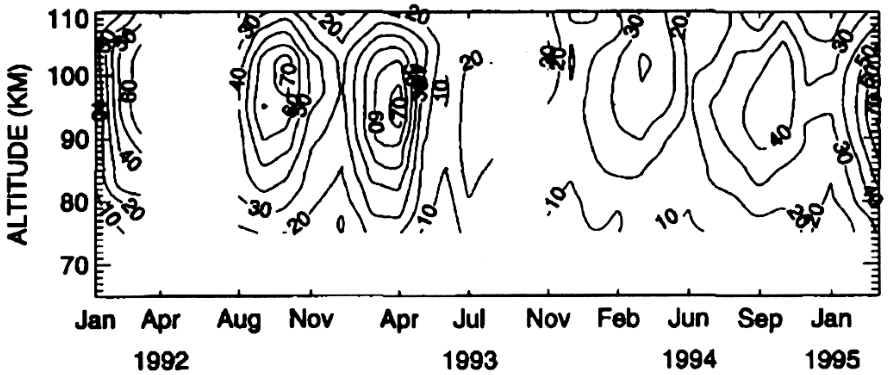
Data assimilation would clearly get around this problem.

McLandress et al (2006)

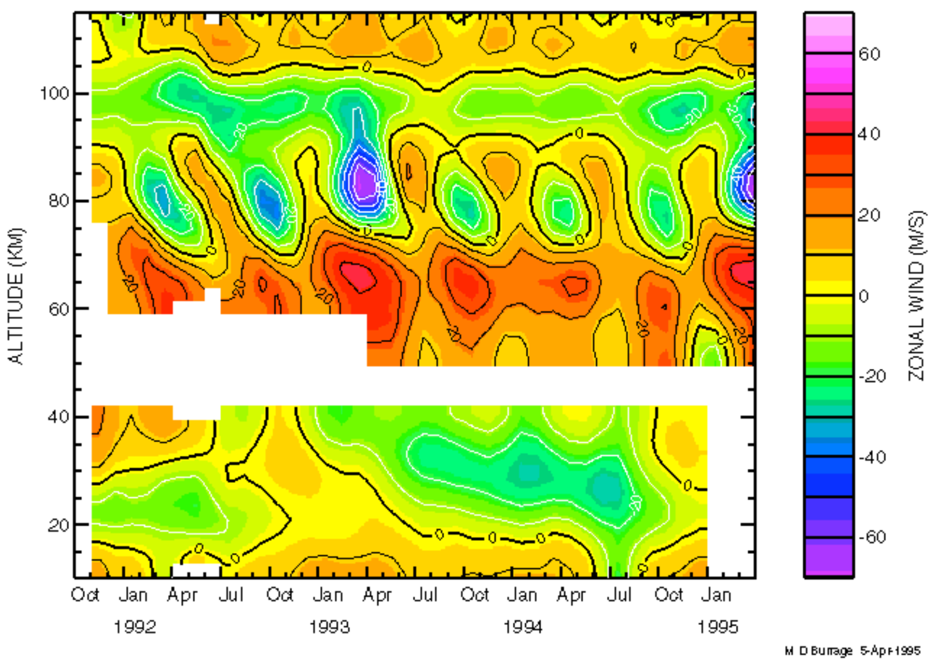
The End

Extra slides

HRDI Observations



HRDI background zonal wind at the equator

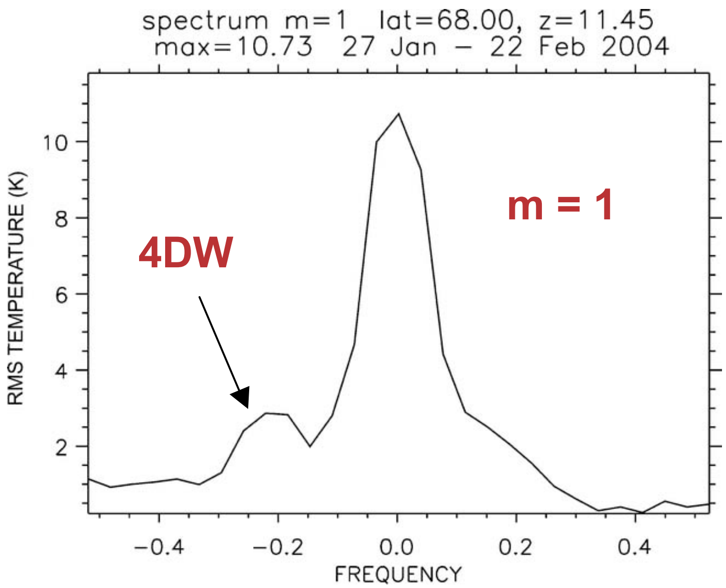


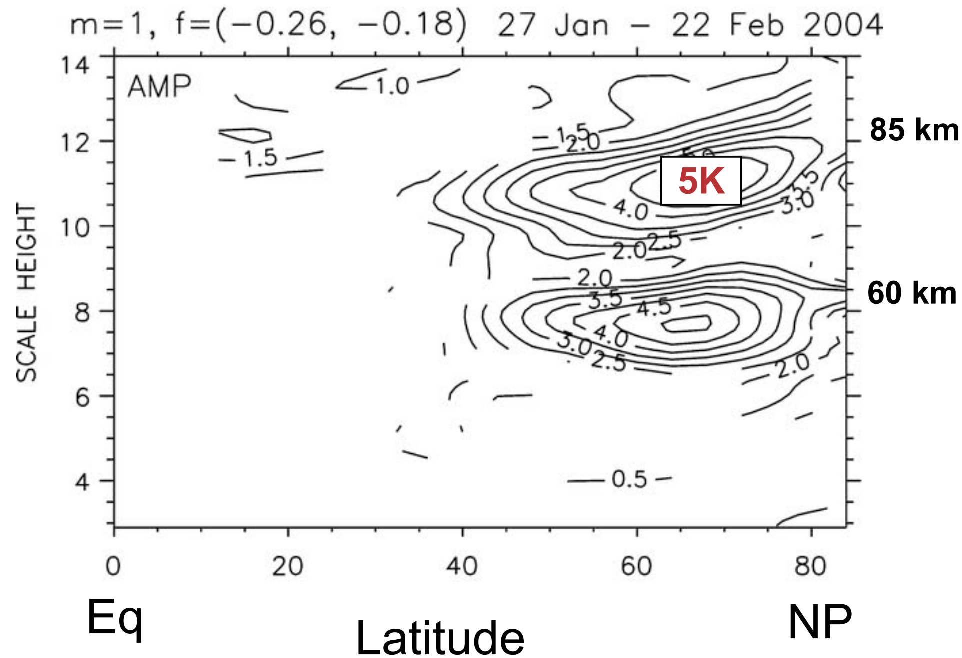
Interannual variation of tidal amplitude (strong in 1992 & 93 weak in 1994 & 95) - is it related to the stratospheric zonal wind QBO?

Lieberman (JATP 1997, top)

Burrage et al. (JGR 1996, bottom)

Four-Day Wave

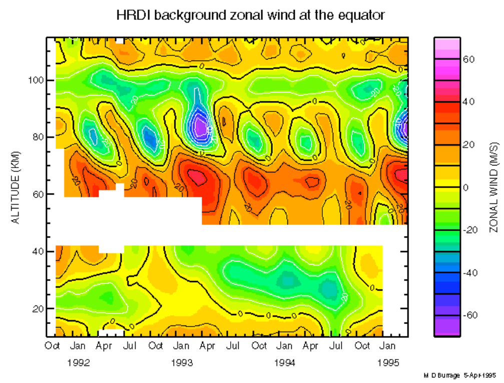


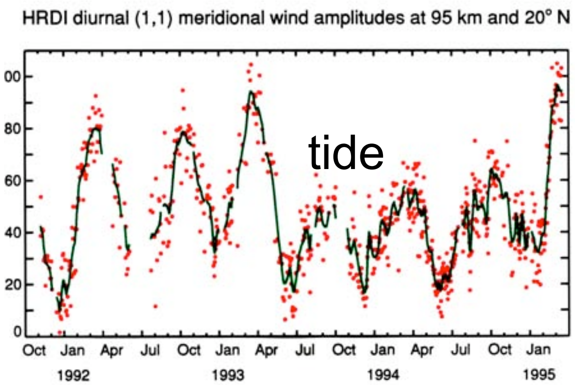


Garcia et al (2005)

Interannual variations of the migrating diurnal tide

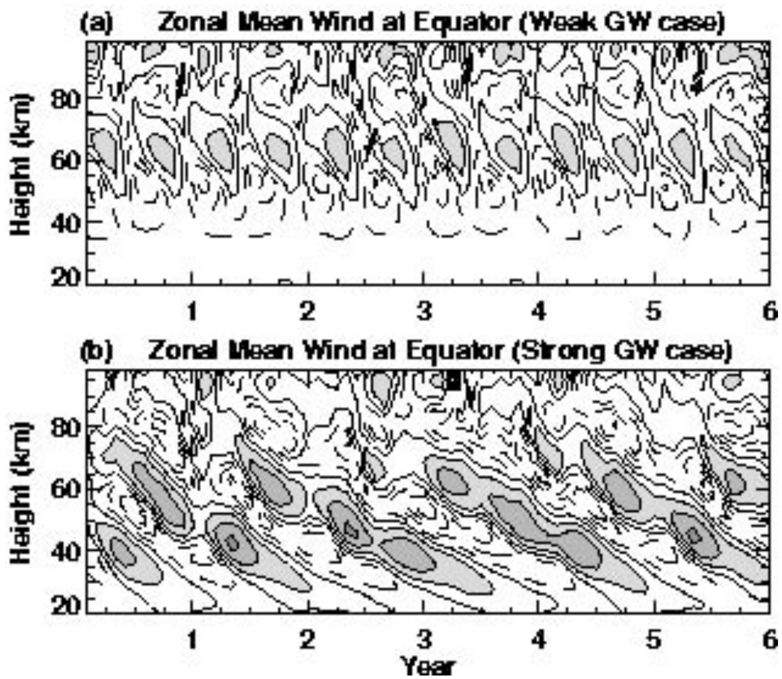
Mean winds

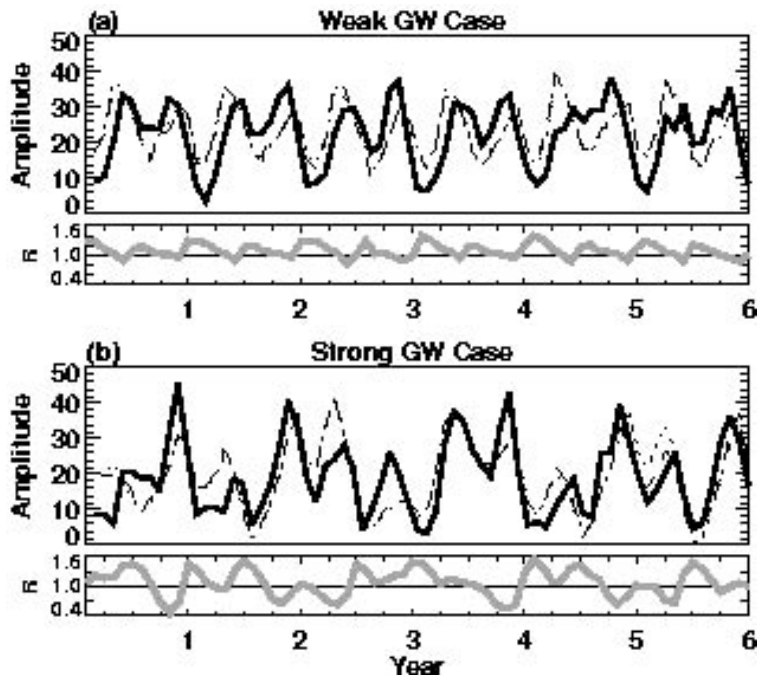




tide

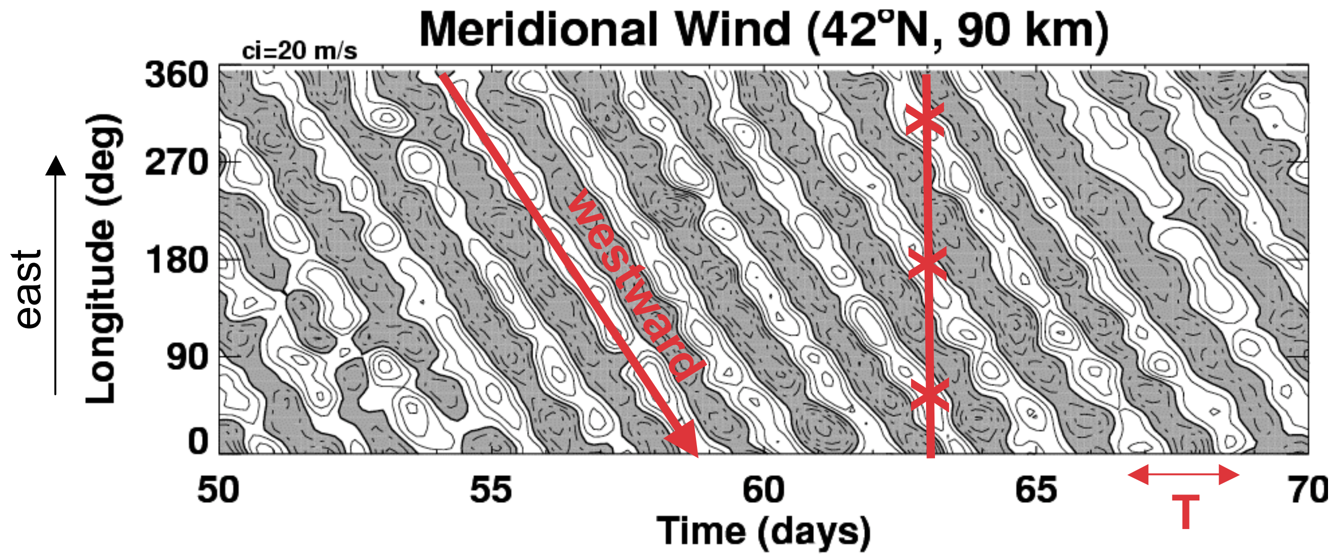
Burrage (GRL 1995)
- HRDI data

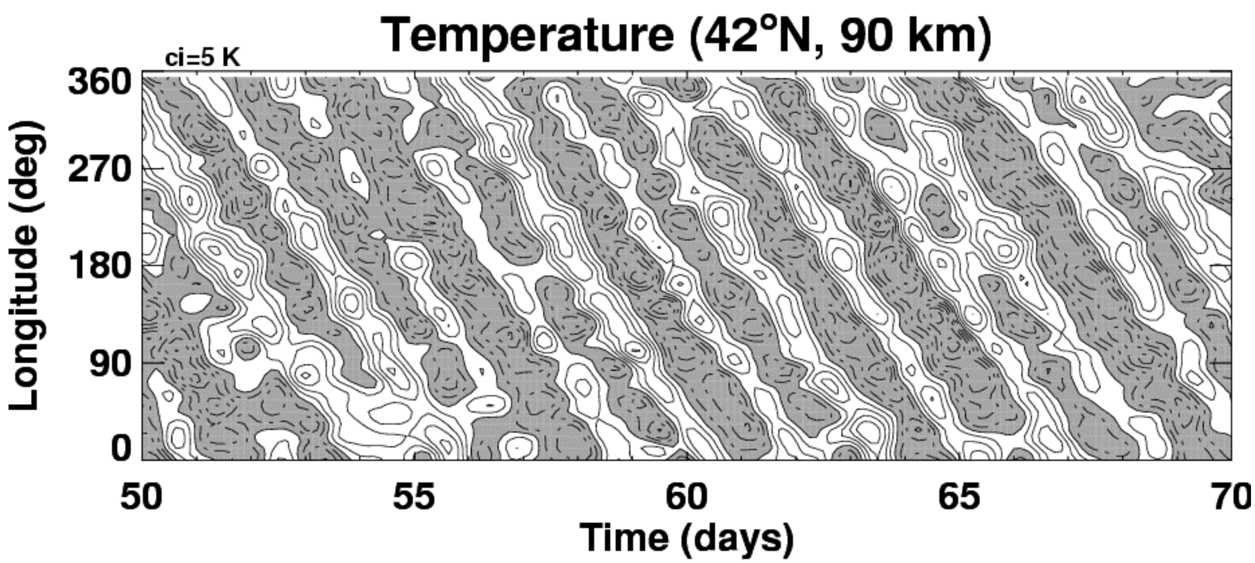




McLandress (GRL 2002)

Two-day wave



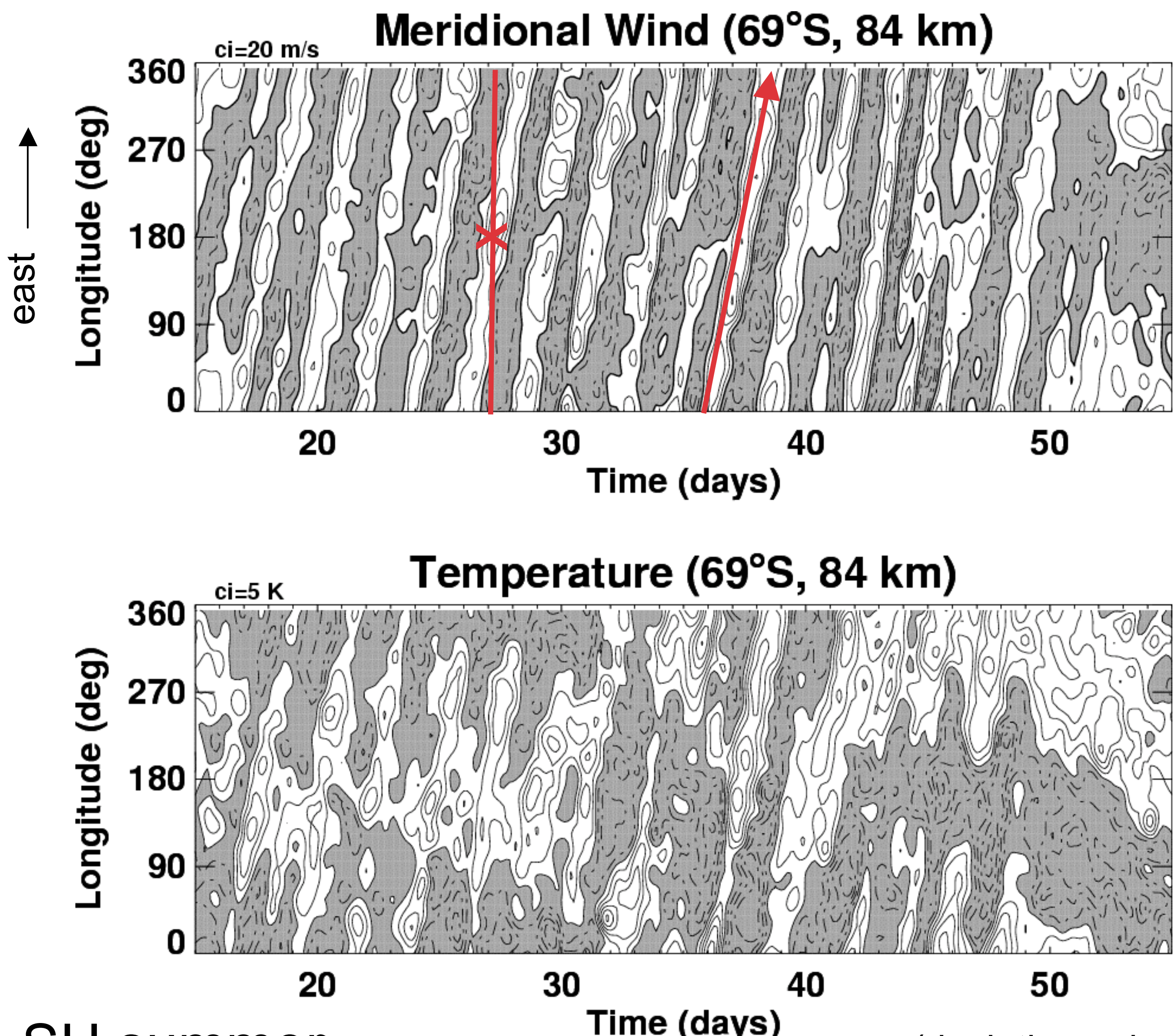


- westward propagating
- period T ~ 1.7 days
- zonal wave 3

NH summer

(deviations about zonal means)

Four-day wave

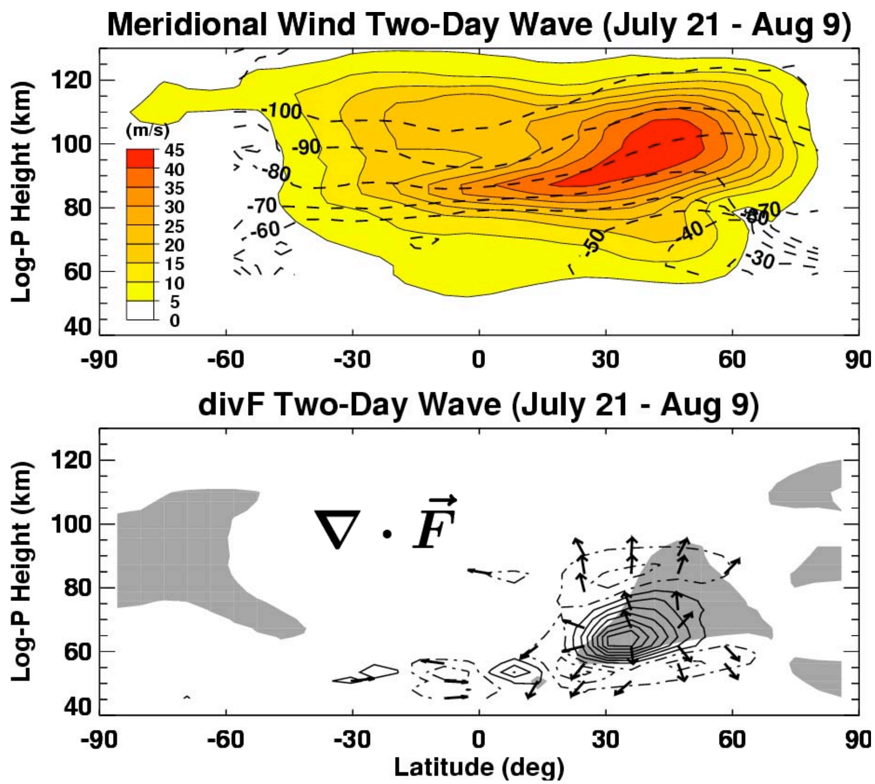


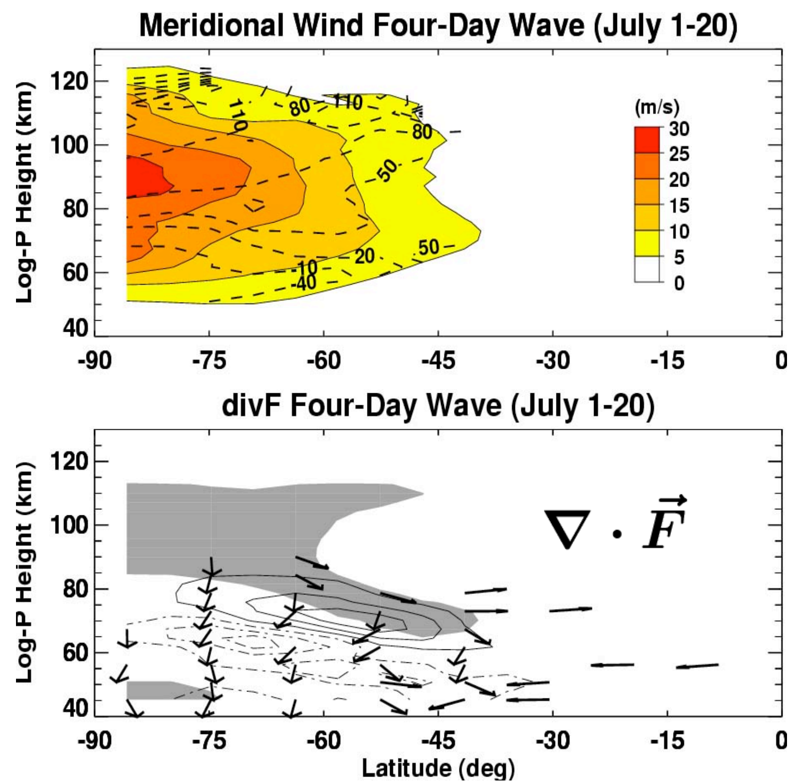
- eastward propagating
- period ~ 2-4 days
- zonal wave 1

SH summer

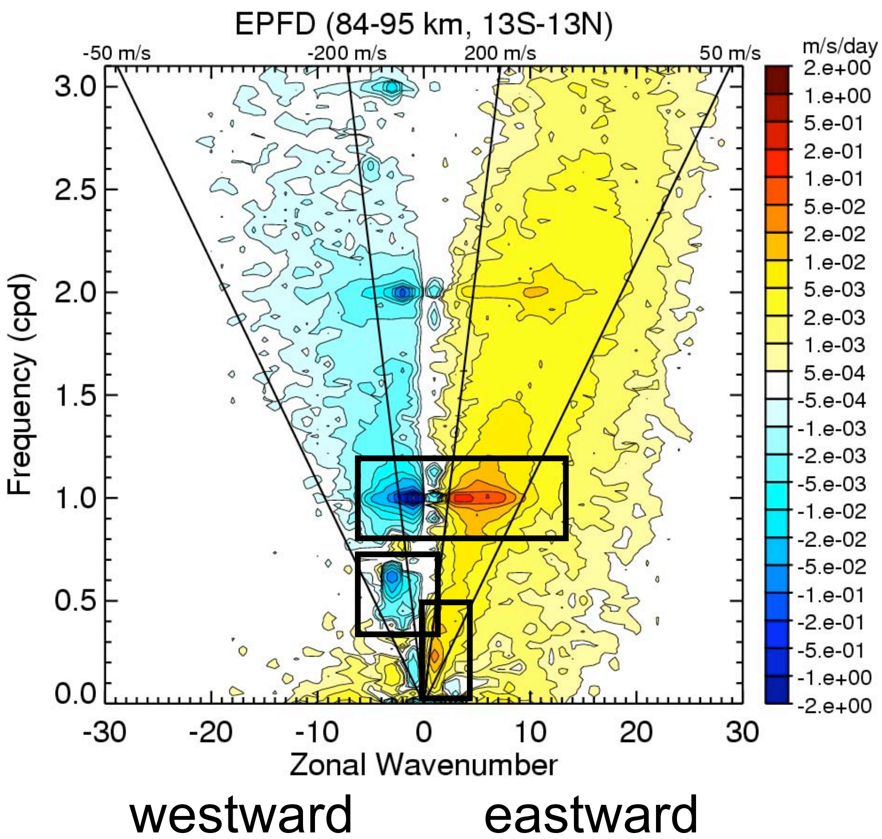
(deviations about zonal means)

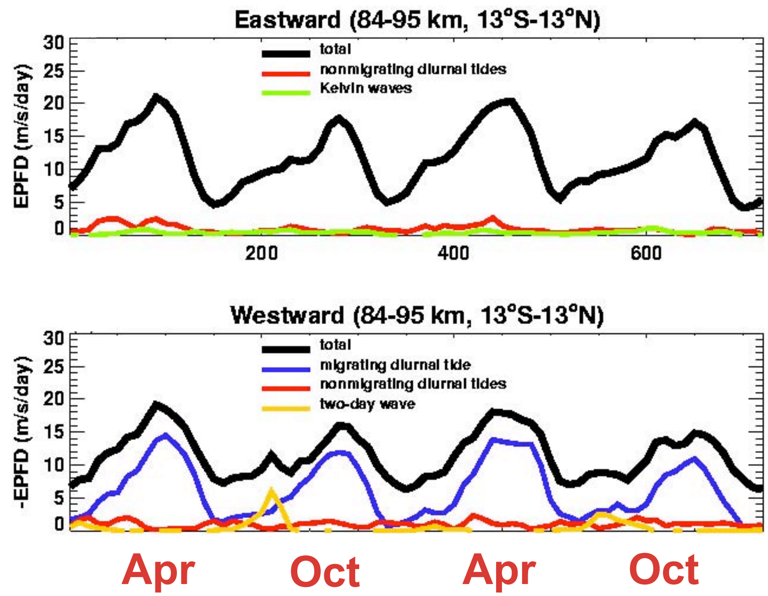
two-day wave **four-day wave**





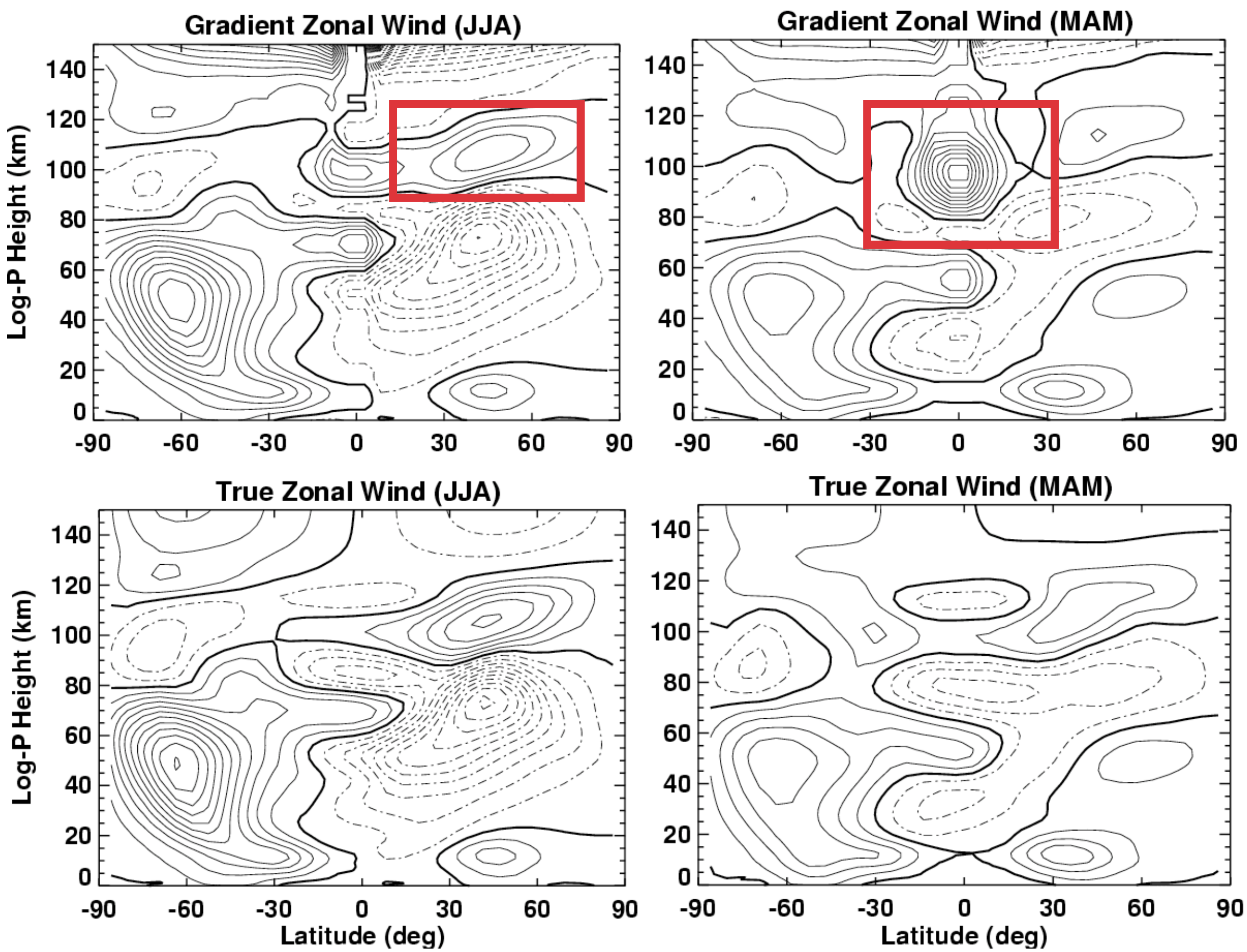
Equatorial wave-forcing in CMAM





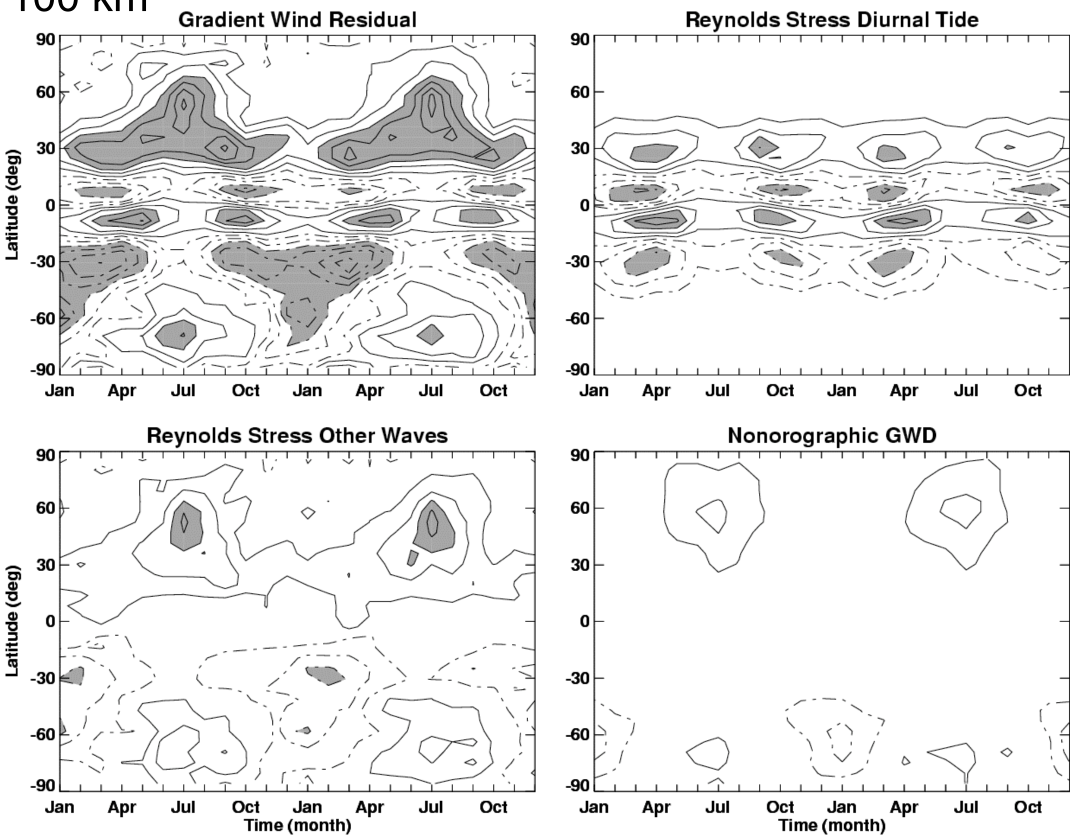
McLandress et al (2006)

Gradient wind balance



Gradient wind equation: $$f\bar{u}_g + \bar{u}_g^2 \frac{\tan\phi}{a} + \frac{1}{a}\frac{\partial\bar{\Phi}}{\partial\phi} = 0$$

100 km



Migrating diurnal tide is responsible for gradient wind imbalance at low latitudes

⇒ strongest at equinox

⇒ reason for anomalous gradient wind westerlies in equinox.

$$f\bar{u} + \bar{u}^2 \frac{\tan\phi}{a} + \frac{1}{a}\frac{\partial\bar{\Phi}}{\partial\phi} = \bar{R} + \bar{F}_v$$

$$\bar{R} = -\overline{u'u'}\,\frac{\tan\phi}{a} - \frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}\left(\overline{v'v'}\cos\phi\right) - \frac{1}{\rho_o}\frac{\partial}{\partial z}\left(\rho_o\,\overline{v'w'}\right)$$

McLandress et al (2006)

Wave sources

- *Solar heating* ⇒ migrating tides.
- *Convection* ⇒ migrating and non-migrating tides, equatorial waves (e.g., Kelvin waves), gravity waves.
- *Topography* ⇒ quasi-stationary Rossby waves & gravity waves.
- *In-situ instability* ⇒ normal-modes (e.g., two-day wave).